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(54) IMPROVEMENTS IN OR RELATING TO FRICTION WELDING

(71) We, MITSUBISHI JIDOSHA KOGYO KABUSHIKI KAISHA, a Japanese body corporate, of 33—8, Shiba 5-chome, Minato-ku, Tokyo, Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a method of friction welding in which two coaxial bodies to be welded together are brought into relative rotation and pressed against each other to achieve the welding by making use of the heat generated by friction at the area of contact, and also to apparatus for carrying out the method.

Heretofore, in a friction welding machine, one of the bodies to be welded in rotated by means of a prime motor, while the other body to be welded is pressed against the one body in the direction of the rotational axis by means of an hydraulic device. When the heat generated by friction at the areas of contact between the bodies has reached a predetermined amount sufficient to melt the areas of contact to weld them together, the relative rotation between the bodies is suddenly ceased, so that the bodies weld together. However, since the period over which the relative rotation stops is very short, of the order of 0.2 to 1 second, it is difficult in practice correctly to position the two bodies about the rotational axis so that they adopt a desired relative angular position. Therefore, it is difficult to join two bodies to be welded in a predetermined relative position by means of the known friction welding machine, and consequently, the known friction welding machine is useful only to weld bodies where the relative angular position between the bodies is not very important; thus the usefulness of the known friction welding machine is limited.

According to one aspect of the present invention there is provided a method of friction welding two bodies in a predetermined angular position with respect to each other which comprises (i) a friction step, in which the two bodies to be welded are pushed against each other with a predetermined pressure while rotating relative to one another about a common axis and, when sufficient heat to plasticize or melt the bodies to be welded has been generated at the area of contact, the relative rotational speed of the bodies is reduced to zero while the pressure between the bodies is maintained; (ii) a sensing step, in which simultaneously with completion of the reduction of the relative rotational speed between the bodies to zero in the friction step, it is sensed whether the bodies are in the predetermined angular position (iii) if necessary, a correction step in which the bodies to be welded are quickly rotated relatively about the axis of rotation to assume the predetermined angular position; and (iv) an upset step, in which the bodies are pushed against each other with a pressure which is equal to or greater than the pressure applied during the friction step.

The critical correction time is the maximum period of time which the correction step can take if a weld is to be obtained which is equal in strength to the base metal. The critical correction time can be increased by applying pressure to the bodies during the correction step. It is therefore preferred to apply pressure to the bodies during the correction step. The pressure preferably has a value between zero and the pressure to be applied during the upset step and it can be constant or it can vary during the time taken for the correction step.

According to a further aspect of the present invention there is provided apparatus for friction welding two bodies in a predetermined angular position with respect to each other which apparatus comprises means for holding two coaxial bodies to be welded and pushing them together while rotating the one body relative to the other to generate heat for welding, means for stopping the relative rotation of the bodies, means for sensing the rela-

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tive angular position of the bodies and, if necessary, bringing the bodies into the predetermined angular position and means for pushing the bodies against each other with a pressure which is equal to or greater than that applied when the bodies are rotated to generate heat.

Any corrective rotation required to bring the bodies into the predetermined relative angular position, can be carried out by means of an hydraulic device, for example a pinion mounted on a rotary shaft which is rotationally driven by a rack integrally connected to an hydraulic piston, or an electric motor driving a rotary shaft. In a preferred embodiment, the sensing of the relative angular position and any corrective rotation are achieved by means of a pair of positioning members having tooth shaped cam profies which can mesh to bring the bodies into the predetermined relative angular position.

In one embodiment of the apparatus there are provided positioning members which have a structure devised in such manner that the impact force upon engagement of said positioning members may be dispersed or softened to reduce considerably the force of the impact applied to said tooth profiles.

The invention will be further illustrated by reference to the accompanying drawings showing, by way of example, various embodiments of the invention, in which:

Figure 1 is a longitudinal cross-section view of a known apparatus for friction welding;

Figure 2 is a schematic diagram explaining the operation of the apparatus shown in Figure 1;

Figure 3 is a longitudinal cross-section view illustrating one preferred embodiment of the present invention;

Figure 4 is a perspective view of the positioning members used in the embodiment shown in Figure 3;

Figure 5 is a developed view showing the operation of the positioning members shown in Figure 4;

Figure 6 is a schematic diagram explaining the operation of the embodiment shown in Figures 3, 4 and 5;

Figure 7 is a diagram showing various different tooth profiles for the positioning members;

Figure 8 is a longitudinal cross-section view similar to Figure 3 of another preferred embodiment of an apparatus for friction welding in accordance with the present invention;

Figure 9A to 9F show various modes of the pressure cycle during the period of the correction step in the method according to the present invention;

Figures 10 to 15, respectively, are schematic diagrams for explaining some embodiments of the method according to the present invention;

Figures 16 and 17, respectively, are perspective views showing examples of the positioning members having a multi-layer of tooth profiles formed thereon to reduce force of impacts applied to the tooth profiles; and

Figures 18 to 22 show examples of the positioning members constructed so as to reduce the impact force applied to the tooth profile by the aid of a wedge and a notch,

Figure 18 being a side view partially in cross-section showing the state prior to the beginning of the correction step,

Figure 19 being a side view partially in cross-section showing the state at the beginning of the correction step,

Figure 20 being a side view partially in cross-section showing the state upon completion of the correction step,

Figure 21 being a perspective view of the notched portion, and

Figure 22 being a perspective view of the wedge.

Referring to Figures 1 and 2, there are shown a known friction welding machine and the mode of operation of the machine. In Figure 1, one of the bodies to be welded *b* is affixed to an output side of main shaft *a* which is rotated by means of a prime motor *c*. The other body to be welded *f* is affixed to a table *e* which is pushed in its axial direction by means of an hydraulic device *g*. When the heat generated by friction at the areas where the bodies are in contact with each other has reached a predetermined value, the rotation of the body *b* is quickly stopped by actuating brake means *i*, associated with a clutch, to weld both bodies together. However, as will be seen from Figure 2, since the known friction welding machine has a very short braking time of the order of 0.2 to 1.0 second, it was difficult or even substantially impossible to position the respective bodies to be welded about said rotational axis simultaneously with the quick stop of the rotating bodies because of the time lag in the braking action, the inertia of the rotating bodies, and the like. Therefore, it was difficult to join two bodies to be welded in a predetermined relative position. Consequently, the known friction welding machine was useful only for welding bodies where the relative angular position of the bodies was not important and thus the applications for the friction welding machine were limited.

Referring to Figures 3 to 5, reference numeral 1 designates a housing, at the top of which is rotatably mounted an output side of main shaft 2. At the inner end of said main shaft 2 is fixedly secured one of the bodies to be welded 3 by the intermediary of a rotor side chuck 4. The outer end of the outpute side of main shaft 2 is coupled to a main shaft 6 by the intermediary of brake

means 5 associated with a clutch, and the other end of said main shaft 6 is in turn coupled to a prime motor 7. When the said clutch is disconnected, it breaks the transmission of rotating torque from the prime mover 7 and the brake 5 is actuated to cause the rotation of the output side of main shaft 2 to cease quickly. Thereafter it allows the main shaft 2 to take an unbraked state (a freely rotatable state) at once. On a sliding guide 1*a* formed in the middle portion of the inner surface of said housing 1 is mounted, so as to be movable only in the axial direction, a slide member 8, for corrective rotation. Also within the slide member 8 is mounted another slide member 9 for pushing the body to be welded, the slide member 9 being movable only in the axial direction. At one end of said slide member 9 the other body 10 to be welded is fixedly secured by the intermediary of a stator side chuck 11, the body 10 being disposed opposite to the body 3. The other end of the slide member 9 is coupled to an hydraulic cylinder 12 for pushing said body to be welded. Around the inner protrusion of said output side of main shaft 2 there is formed integrally a positioning member 13 while on the upper surface of said slide member 8 is formed another positioning member 14, integrally with the slide member 8. The lower end of the positioning member 14 and slide member 8 are coupled to an hydraulic cylinder 15 for corrective rotation. On the mutually opposed surfaces of said pair of positioning members 13 and 14 are formed tooth-shaped profiles 13*a* and 14*a*, respectively, said respective tooth-shaped profiles 13*a* and 14*a* being preliminarily arranged in such a manner that when these tooth-shaped profiles are meshed with each other, the said respective bodies 3 and 10 are positioned at predetermined angular positions relative to each other. The tooth-shaped profiles illustrated in Figure 4 are those for use in the manufacture of parts having a symmetry of 180°. The tooth-shaped profiles 13*a* and 14*a* provided on the respective members 13 and 14 may be disposed only one for each.

In operation the body 3 is rotated together with the input side of main shaft 6, brake means 5 associated with the clutch, output side of main shaft 2 and rotor side chuck 4 by means of the prime mover 7. The body 10 is simultaneously pushed in the axial direction together with the slide member 9 to bring the two bodies 3 and 10 into contact with each other, so that these bodies 3 and 10 undergo relative rotation having a r.p.m. of N_1—N_2 (in this case, $N_2=0$). The bodies also experience contact force of pressure P_1, so that heat is generated by friction at the area of contact between the respective bodies 3 and 10, as shown in Figure 6. If this state is maintained for a desired time of t_1, then the area of contact becomes molten and is in a weldable state. During the above-mentioned period of time, the respective tooth-shaped profiles are kept disengaged. When the area of contact is in a weldable state, that is, when the friction step has been completed, the said clutch is disconnected to break the transmission of the rotating torque from the prime mover 7 and the brake 5 is applied so that the output side of main shaft 2 is quickly stopped by the braking action over the braking period of t_2. Simultaneously with the termination of the braking period this main shaft 2 is brought into an unbraked state (a freely rotatable state). The positioning member 14 and slide member 8 are pushed in the axial direction by means of the hydraulic cylinder 15 simultaneously with completion of the abovementioned operation. One tooth-shaped profile 14*a* moves in the axial direction while sliding along the other tooth-shaped profile 13*a*, as illustrated in Figure 5, the positioning member 13 carries out corrective rotation, and during the period when the respective tooth-shaped profiles 13*a* and 14*a* are meshed with each other over a desired time of t_3, the body 3 is subjected to corrective rotation, together with the positioning member 13. Because the respective tooth-shaped profiles 13*a* and 14*a* are preliminarily disposed in such a manner that when they are meshed with each other the bodies 3 and 10 adopt a desired relative position, the bodies 3 and 10 can be joined together at the desired relative position. Subsequent thereto, the joined bodies are subjected to the upset step, and thereby the friction welding is completed. In this way, two bodies 3 and 10 can be joined in a predetermined relationship.

In the illustrated embodiment the positioning member 13 is freely rotatable but immovable axially and the positioning member 14 is movable in the axial direction but does not rotate. However, the invention is not limited to such an arrangement. Apparatus in accordance with the invention can employ an arrangement in which the positioning member 13 is movable in the axial direction while the positioning member 14 is freely rotatable, as illustrated by the arrows in the parentheses ( ) in Figure 5. In addition, if the triangular ended protrusion 13*a*′ of the tooth-shaped profile 13*a* is provided only on either one of the positioning members, this triangular-ended protrusion 13*a*′ makes a surface contact with the side surface of the opposite tooth-shaped profile 14*a* for positioning, even though the tooth-shaped profiles are not completely meshed with each other, so that the impact upon engagement between said positioning members can be reduced to zero or to a very small value.

As shown in Figure 7, the configurations of the tooth-shaped cam profiles are different for the case of one-way corrective rotation

and the case of two-way corrective rotation. Further, the number n of cam profiles on the positioning members varies, depending upon the angle θ° of symmetry of the bodies being welded and being calculated by the formula

$$n=\frac{360^\circ}{\theta^\circ}.$$

In the case of bodies without angular symmetry, i.e. having an angle of symmetry of 360°, the angle of corrective rotation can range between 0° and 360° in the case of one-way corrective rotation.

Because this method of welding is carried out by making use of the heat generated at the friction surface of two bodies to be welded during the friction step, the temperature at the area of contact of the bodies to be welded begins to lower with the passage of time during the corrective rotation for the purpose of positioning the bodies 3 and 10 as described, so that the aforementioned embodiment may possibly have the following disadvantages:

(1) the critical correction time (the maximum permissible time for the correction step if a weld of strength equal to that of the base metal of the bodies to be welded is to be achieved) is short,

(2) when a series of welding operations is carried out, the amount of upset which occurs during the corrective rotation step in different welding operations fluctuates widely, and

(3) the torque required for the corrective rotation step is increased. As the temperature falls, the amount of torque necessary for relative rotation increases.

Especially there occurs a problem that the hot plastic working becomes hard to be carried out normally. If the required time for the correction step exceeds a certain limit, i.e. the above-mentioned critical correction time, then the strength of the weld may be badly affected. Therefore, unless the correction step is completed within the critical correction time, stable welding cannot be obtained. In practice it is desirable that the critical correction time should be as long as possible. In other words, the longer the critical correction time the slower the correction rotational speed can be chosen, and accordingly there arises the advantage that the torque required for the corrective rotation can be small. This is desirable for joining bodies which are of such shape and made of such materials that they lose heat rapidly and for joining materials which have a high lower limit of temperature at which they are suitable for hot plastic working. Furthermore the assurance of corrective rotation within the critical correction time is facilitated by a longer critical correction time regardless of the amount of time required for corrective rotation by the corrective rotation means. If the variation in the amount of upset during the correction step can be reduced, then the precision for the friction welding may be enhanced, and if the rotating torque for correction can be reduced, then the driving power of the corrective rotation means may be reduced.

In view of the above-mentioned situation, the present inventors have conducted various tests and investigations for the purpose of improving the various short-comings in the embodiment of Figure 3, and as a result it has been recognized that said purpose can be achieved by setting the pressure P_3 applied to the bodies to be welded during the correction step and either by maintaining this pressure P_3 at any constant value within the limits $0<P_3<P_2$ depending upon the shape, material and heat generation of the bodies to be welded, or by varying the pressure P_3, with the passage of time in the correction step, within the limits $0<P_3<P_2$.

A second form of the method of the present invention has been provided based on the results of the said tests and investigations. This permits a method of friction welding comprising a friction step in which two bodies to be welded are pushed against each other with a predetermined applied pressure whilst undergoing relative rotation until sufficient heat to plasticize or melt the bodies has been generated at the area of contact, the relative rotational speed of said bodies is reduced to zero while the applied pressure is maintained; sensing and correction steps in which as soon as the relative rotational speed has been reduced to zero, the bodies to be welded are subjected to any necessary corrective relative rotation quickly through an angle between 0° and 360° as measured in either one direction; and an upset step in which the respective bodies are pushed against each other with an applied pressure equal to or larger than the applied pressure during said friction step; characterized in that the pressure applied during the correction step is maintained at any constant value between zero and the pressure to be applied during said upset step.

In a third form of the present invention there is provided a positioning friction welding method, in which the pressure during said correction step is varied in various manners, with the passage of time in the correction step, between zero and the pressure to be applied during said upset step.

Apparatus to be used for practising the aforementioned methods will now be described with reference to Figure 8. In Figure 8, the same components as those shown in Figure 3 are given like reference numerals, and the description therefor will be omitted.

In contrast to the apparatus shown in Figure 3, the apparatus shown in Figure 8 has a control device 12*a* for the hydraulic means, which is connected to the hydraulic means

12 in such manner that the hydraulic pressure in said hydraulic means 12 can be controlled within limits by means of said control device 12*a*.

If the angle of corrective rotation is zero, if the pressure P_2 is selected to be higher than the pressure P_1 a forging effect is produced similar to that caused by corrective rotation and thus the welding strength is increased with respect to the case when $P_2=P_1$. Therefore the allowable correction time can be prolonged. Since the amount of upset during the correction step differs in accordance with the amount of angle of corrective rotation, it causes variation in the total length of the welded body, and such variation is not desirable. The reduction of this variation can be readily achieved by employing a relatively higher applied pressure (P_2 higher than P_1) which results in the change in the axial dimension large than that caused by the corrective rotation. In addition, since the temperature lowers as the time elapses within the period T_3 and thereby the torque required for the corrective rotation is increased, the corrective rotion can be achieved with a smaller torque by selecting the pressure P_2 lower than the pressure P_1. Depending upon which one of the above effects is expected, various cycles disclosed in Fig. 9 can be established.

Variable examples will be described with reference to the step diagram shown in Figure 9 and the step diagrams of Figures 10 to 15.

Example 1

(Corresponding to the case of Figure 10, corresponding to (3) in Figure 9B). The bodies to be welded and the conditions of this example are as follows:

Bodies to be welded:
20 mm $\phi\times100$ mm, S33C material

Welding conditions:
$P_1=3.2$ Kg/mm^2
$P_2=11.5$ Kg/mm^2
$P_3=4.7$ Kg/mm^2—5.4 Kg/mm^2
(P_3') (P_3'')
$t_1+t_2=20$ seconds
$t_4=7$ seconds
$t_3=3$ seconds (2 seconds, if $P_3=P_1$)

Since the friction step and the upset step have no distinct difference from those in the method described with reference to Figure 3, the description of these steps is omitted and a description will be made in the following only with respect to the correction step. Although it is the same as the previous method that in this method also, as soon as the friction step has been completed the correction step is commenced, according to this method immediately after completion of the friction step the control device 12*a* is caused to control the hydraulic means 12 for pushing upon welding, to raise the applied pressure P_3 between the respective bodies 3 and 10 to be welded at first up to P_3', and subsequently to continuously vary this pressure upwardly with the passage of time in the correction step until it reaches P_3'' at the termination of the correction step. As a result, the period t_3 of the correction step, which was equal to 2 seconds in the case of the method according to the first embodiment in which $P_3=P_1$ is satisfied, is increased to 3 seconds (increase of 50%), that is, the critical correction time is widely increased. This increase in the critical correction time has been observed experimentally and is believed to arise for the following reasons: During correction the joint faces, which have finished the friction step, mutually exert plastic working (forging) effect upon each other due to the relative displacement in the circumferential and axial directions (upset effect). If the angle of corrective rotation is 0°, this effect does not occur and the joint strength is less. However, if the applied pressure P_2 is greater than P_1 then a forging effect occurs similar to that caused by corrective rotation. Hence the joint strength is increased and the critical correction time is increased. The variation of the amount of upset is reduced to ±0.5 mm in contrast to the value of ±1.0 mm in the case of the method according to the first embodiment.

Example 2

The bodies to be welded as well as the welding conditions are the same as those of Example 1 shown in Figure 10 except that the applied pressure P_3 is maintained at a constant value of 147% of the pressure P_1. Figure 11 is a step diagram corresponding to the case of (4) in Figure 9B. In this case also, the critical correction time t_3 was increased from 2 seconds to 3 seconds.

Example 3

The critical correction time (the maximum permissible time for attaining a strength equal to that of the base metal of the bodies to be welded) is increased.

Control Process:

The bodies to be welded and the welding conditions were as in Example 1 except that the applied pressure P_3 is increased from the value P_1 with the lapse of time in the correction step, within the scope of

$$P_1<P_3\leqq P_2$$

Examples of this Cycle:
Fig. 9A (1), (2), (3); Fig. (1), (2), (3), (4); Fig. 9C (1), (2), (3), (5).

More detailed Data for Fig. 9B (4):
When P_3 was increased to 147% of P_1

and kept at that constant pressure, then the critical correction time was increased from 2 seconds to 3 seconds.

Example 4

Variation in the amount of upset during the correction step is reduced.

Control process:

The applied pressure P_3 was controlled so that the upset velocity (deformation velocity) of the two bodies to be welded during the correction step was kept constant.

Examples of this Cycle:

Fig. 9A (1), (2), (3); Fig. 9B (1), (2), (3); Fig. 9C (1), (2), (3).

More detailed Data for Fig. 9A (3):

The bodies to be welded and the welding conditions were as follows:

Bodies to be welded:
20 mm $\phi \times 100$ mm (S33C) 2 pieces

Welding Conditions:
$P_3 = 3.2$—4.0 Kg/mm^2
$T_3 = 2$ seconds
$P_1 = 3.2$ Kg/mm^2
$P_2 = 11.5$ Kg/mm^2
$T_1 = 20$ seconds
$T_4 = 7$ seconds

When P_3 was increased by 75% of P_1 starting from P_1 with the lapse of time during the period $T_3 = 2$ seconds, then the variation in the amount of upset was reduced from ± 1.00 mm to ± 0.5 mm. The welding operation is further illustrated in Figure 12.

Example 5

Torque for the corrective rotation is reduced.

Control process:

The applied pressure P_3 was controlled so that at least in the first part of the correction step, the pressure P_3 was reduced to a value less than P_1, that is,

$$0 < P_3 < P_1.$$

Examples of this Cycle:

Fig. 9D (1), (2), (3); Fig. 9E (1), (2), (3), (4); Fig. 9F (1), (2), (3), (4).

More detailed Data for Fig. 9E (4):

Welding Conditions:
$P_1 = 3.2$ Kg/mm^2
$P_2 = 11.5$ Kg/mm^2
$P_3 = 3.2$ & 1.9 Kg/mm^2
$T_1 = 20$ seconds
$T_4 = 7$ seconds
$T_3 = 1.5$ seconds

Though the torque required for the corrective rotation (the maximum value) was 27 Kg.m in the case of $P_3 = P_1$, said torque was reduced to 18 Kg.m when P_3 was reduced by 40% of P_1. The welding operation is further illustrated in Figure 13.

Example 6

The critical correction time is increased and also variation in the amount of upset is reduced.

Control Process:

The applied pressure P_3 was hydraulically controlled within the range of

$$P_1 < P_3 \leqq P_2$$

with the lapse of time during the correction step so that the upset velocity of the bodies to be welded was kept constant.

Examples of this Cycle:

Fig. 9A (1), (2), (3); Fig. 9B (1), (2), (3); Fig. 9C (1), (2), (3).

More detailed Data for Fig. 9B (3):

The welding conditions were as follows:

Bodies to be welded:
20 mm $\phi \times 100$ mm (S33C) 2 pieces
$P_1 = 3.2$ Kg/mm^2
$P_2 = 11.5$ Kg/mm^2
$P_3 = 4.7$—5.4 Kg/mm^2
$T_1 = 20$ seconds
$T_4 = 7$ seconds
$T_3 = 3$ seconds

When the pressure P_3 was increased with the lapse of time within T_3 from the value 147% of P_1 up to the value 170% of P_1, then the critical correction time was increased from 2 seconds to 3 seconds, and the fluctuation in the amount of upset was reduced from ± 1.00 mm to ± 0.5 mm. The welding conditions are further illustrated in Figure 14.

Example 7

The critical correction time is increased and also the torque for corrective rotation is reduced.

Control Process:

The applied pressure P_3 was varied within the range of $0 < P_3 \leqq P_2$ with the lapse of time during the correction step.

Examples of this Cycle:

Fig. 9A (4); Fig. 9B (4), (5); Fig. 9C (4); Fig. 9D (1), (2); Fig. 9E (1), (2), (4); Fig. 9F (1), (2).

More detailed Data for Fig. 9B (5):
The welding conditions were as follows:

P_3 = 4.7 Kg/mm²—1 sec. and then reduced to 1.9 Kg/mm² within 1.5 sec.
T_3 = 2.5 sec.
P_1 = 3.2 Kg/mm²
P_2 = 11.5 Kg/mm²
T_1 = 20 sec.
T_4 = 7 sec.

In the first part of the correction step, the pressure P_3 is increased to 147% of P_1, and in the second part of the correction step the pressure P_3 is reduced below P_1 by 40% of P_1. The critical correction time was increased from 2 seconds to 2.5 seconds, and the torque for corrective rotation was reduced from 27 Kg.m to 22 Kg.m. The operation is further illustrated in Figure 15.

While only one basic example for each of the five cases has been described in detail in Examples 3 to 7, the reproductibility of the effects to be obtained from other pressure cycles is quite sure, and so we omit the demonstration of other cycles.

In the apparatuses used in the aforementioned three embodiments, two tooth-shaped cam profiles 13*a*, 13*a* and two tooth-shaped cam profiles 14*a*, 14*a* are employed, and there are two contact points between the tooth-shaped cam profiles 13*a* and 14*a*, so that large impact forces are concentrated at these contact points. In order to avoid such a disadvantage, positioning members formed in a multi-layer configuration having the tooth-shaped cam profiles staggered in position as shown in Figure 16, may be employed. The impact forces applied to the extremities of the tooth-shaped cam profiled upon being meshed with each other, can be dispersed over the multi-layer teeth. Referring to Figure 16, reference numerals 13 and 14 designate positioning members, respectively, having tooth-shaped profiles similar to those shown in Figure 4. In these positioning members, members 13″ and 14″ concentrically fitted in the members 13 and 14, respectively, are provided having the angular positions of the tooth-shaped cam profiles 13*a*″ and 14*a*″, respectively, displaced relative to the tooth-shaped cam profiles 13*a* and 14*a* so that these tooth-shaped cam profiles may be positioned as a whole at equal angular intervals along the circumference, and thereby positioning members having a multi-layer tooth-shaped cam profile are constructed. It is to be noted that the number of tooth-shaped cam profiles in these members may be one or any more number (2 in Figure 16). In the case of a single tooth-shaped cam profile for each member, there are provided positioning members having multi-layer tooth-shaped cam profiles in which the respective cylindrical members are fitted to each other with the tooth-shaped profiles displaced by 180°, and these are shown in Figure 17 as a perspective view.

According to these modifications, the impact force is reduced to about 1/2 with respect to the members not employing the double layer structure, the impact forces applied to the shafts having these members mounted thereon are dispersed, and accordingly the buckling load may be reduced.

However, the positioning members 13 and 14 described with reference to Figure 4 as well as the positioning members shown in Figures 16 and 17, have a disadvantage that when the extremities of the tooth-shaped cam profiles make contact with the tooth-shaped cam profiles on the opposite side, the loading stress applied to the extremities of the cam portions are very large, and therefore, the tooth-shaped cam profiles are apt to be damaged and thus the durability is low. In order to mitigate the loading stress upon contact of the extremities of the tooth-shaped cam profiles, the following solution may be practised. More particularly, the stress applied upon contact of the tooth-shaped cam profiles of the respective positioning members may be mitigated by providing a wedge or a notch within a guide for a stator side positioning member, also providing a notch or a wedge to be meshed with said wedge or said notch, respectively, in the stator side positioning member, and maintaining said stator side positioning member and said guide therefor, until the tooth-shaped profiles make contact with each other, in such relation that said wedge and notch retain some looseness in the axial direction so as to allow a minute angle of rotation of said stator side positioning member about its axis.

One example of the positioning members constructed in such manner is described with reference to Figures 18 to 22. Reference numeral 16 designates a guide for a stator side positioning member, which is subjected to a pushing force I in the axial direction from the pusher hydraulic device 12 for welding illustrated in Figures 3 and 8, and said guide 16 is fitted with a stator side positioning member 14. Reference numeral 13 designates a rotor side positioning member similar to that shown in Figure 4. On the inner bottom surface of the guide 16 is provided a wedge 17 having slant faces 19 in protrusion, while in the stator side positioning member 14 is provided a notch 18 having slant faces 20 corresponding to the slant faces 19 of the wedge 17 on the guide 16. While the wedge 17 is provided on the guide 16 and the notch 18 is provided in the member in the illustrated example, of course the wedge could be in the member and the notch on the guide.

Positioning members formed with only one tooth-shaped profile 13*a*′ have been illustrated

as the positioning members 13 and 14 in Figures 18 to 22 for the sake of simplicity of the description, but these may be members having two tooth-shaped profiles as shown in Figure 4 or as members having more tooth-shaped profiles. Alternatively, they may, of course, be formed as members having multi-layer type tooth-shaped profiles as illustrated in Figures 16 and 17.

Figure 18 shows the state where the tooth-shaped profile of the rotor side positioning member 13 is substantially 180° out-of-phase with respect to the notch in the rotor side of positioning member 14 when the rotor side of positioning member 13 has been braked and stopped after completion of the friction heating step as described previously. In this case, between the wedge 17 on the guide 16 and the notch 18 in the member 14, is left looseness L in the axial direction and *l* in the circumferential direction. If the guide 16 is pushed by the hydraulic device 12 in the direction shown by arrow I, then the engagement faces of the respective positioning members 13 and 14 collide with each other, resulting in a torsional torque therebetween. Accordingly, the stator side positioning member 14 engages with the guide 16 so that the slant face 19 of the wedge 17 may abut against the slant face 20 of the notch 18 as shown in Figure 19.

If the stator side positioning member 14 is further pushed in the direction shown by the arrow I, then the rotor side positioning member 13 is subjected to corrective rotation while sliding along the engagement face 14*a* of the stator side positioning member 14. Simultaneously therewith, the slant face 19 of the wedge 17 in the guide 16 and the slant face 20 of the notch 18 in the stator side positioning member 14 slide along with each other, and thereby said positioning member 14 *per se* is subjected to corrective rotation to complete the coupling between the three members 13, 14 and 16 as illustrated in Figure 20.

As described, by making the wedge or notch provided on the stator side positioning member and the notch or wedge, respectively, provided on the guide for supporting said positioning member cooperate with each other, and by retaining minute looseness between the guide and the stator side positioning member upon engagement between the tooth-shaped profiles, it is enabled to mitigate the impact upon engagement and to lengthen the life of the tooth-shaped profiles.

WHAT WE CLAIM IS:—

1. A method of friction welding two bodies in a predetermined angular position with respect to each other which comprises (i) a friction step, in which the two bodies to be welded are pushed against each other with a predetermined pressure while rotating relative to one another about a common axis and, when sufficient heat to plasticize or melt the bodies to be welded has been generated at the area of contact, the relative rotational speed of the bodies is reduced to zero while the pressure between the bodies is maintained; (ii) a sensing step, in which simultaneously with completion of the reduction of the relative rotational speed between the bodies to zero in the friction step it is sensed whether the bodies are in the predetermined angular position, (iii) if necessary, a correction step in which the bodies to be welded are quickly rotated relatively about the axis of rotation to assume the predetermined angular position with respect to each other; and (iv) an upset step, in which the bodies are pushed against each other with a pressure which is equal to or greater than the pressure applied during the friction step.

2. A method according to Claim 1, in which pressure is applied to the bodies during the correction step and the pressure is maintained at a constant value between zero and the pressure to be applied during the upset step.

3. A method according to Claim 2, in which the pressure applied during the correction step is equal to the pressure applied during the friction step.

4. A method according to Claim 1, in which pressure is applied to the bodies during the correction step and the pressure is varied between zero and the pressure to be applied during the upset step.

5. Apparatus for friction welding two bodies in a predetermined angular position with respect to each other which apparatus comprises means for holding two coaxial bodies to be welded and for pushing them together while rotating the one body relative to the other to generate heat for welding, means for stopping the relative rotation of the bodies, means for sensing the relative angular position of the bodies and, if necessary, relatively rotating them to bring them into a predetermined relative angular position and means for pushing the bodies against each other with a pressure which is equal to or greater than that applied when the bodies are rotated to generate heat.

6. Apparatus as claimed in Claim 5 which comprises: (i) means for coaxially supporting two bodies to be welded, respectively, and for pushing the bodies against each other while rotating one body relative to the other body; (ii) a pair of positioning members which face each other, which have tooth-shaped cam profiles on their opposed faces and which are secured for rotation with the two bodies, respectively, either one of the positioning members being movable in an axial direction; (iii) further pusher means for pushing one of the positioning members in an axial direction with respect to the other positioning member; and (iv) brake and clutch means for re-

ducing the relative rotational speed between the two bodies to zero after completion of a friction step and simultaneously therewith bringing one of the bodies to be welded into a freely rotatable state; whereby corrective rotation can be carried out by means of the respective tooth-shaped cam profiles of the positioning members engaging with each other when one of the positioning members is pushed in the axial direction by the further pusher means, thereby positioning the bodies to be welded at a predetermined relative position.

7. Apparatus for friction welding as claimed in Claim 6, in which positioning members are provided with tooth-shaped cam profiles on their opposed faces, which are formed in a concentric multi-layer configuration.

8. An apparatus for friction welding as claimed in Claim 6 or 7, in which one of the positioning members is not rotated and is fitted in a positioning member guide, the bottom portion of the guide and the end of the one positioning member opposed to the bottom of the guide being provided with a wedge on one of them and a notch in the other, and the guide and the one positioning member being fitted to each other retaining minute looseness in the axial direction therebetween.

9. A method of friction welding according to Claim 1 substantially as described herein with particular reference to, and as shown in, any of Figures 3 to 22 of the accompanying drawings.

10. An apparatus for friction welding as claimed in Claim 5 substantially as described herein with particular reference to any of Figures 3 to 22 of the accompanying drawings.

11. Bodies welded together by a method according to any one of Claims 1 to 4 and 9 or by means of an apparatus as claimed in any one of Claims 5 to 8 and 10.

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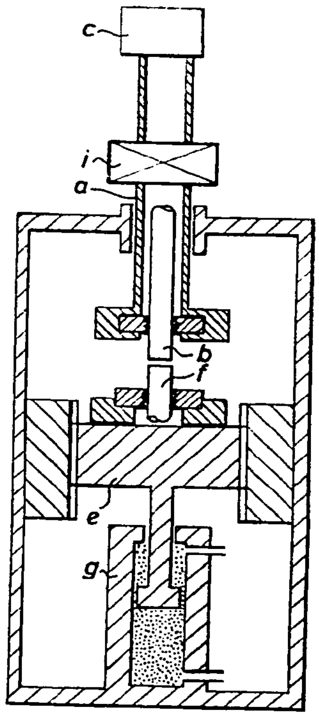


Fig.1.

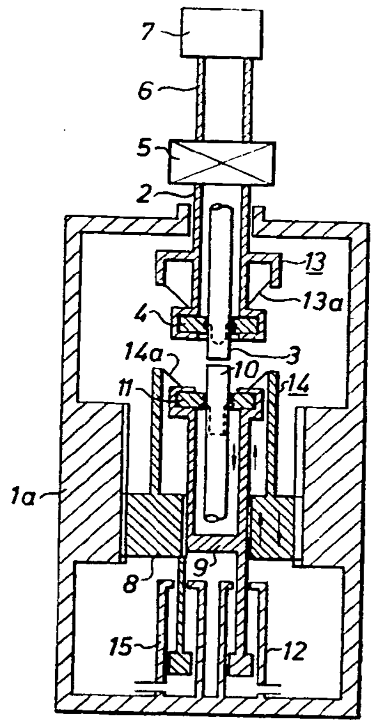


Fig.3.

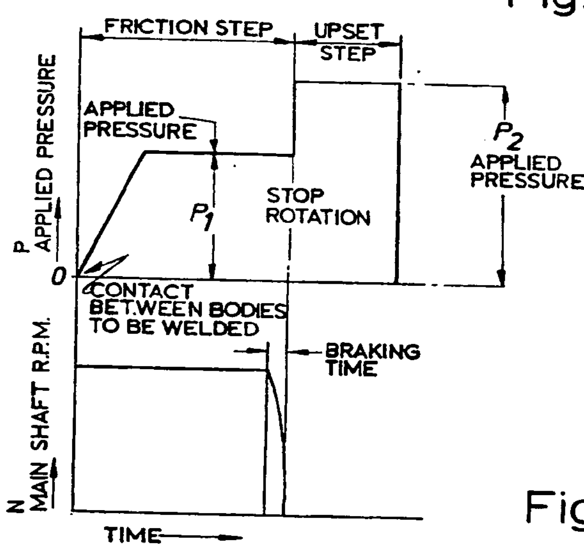


Fig.2.

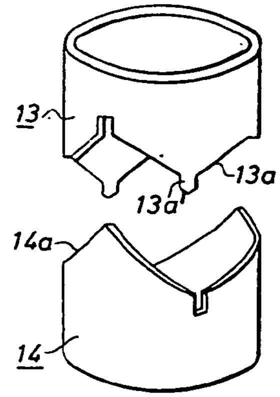


Fig. 4.

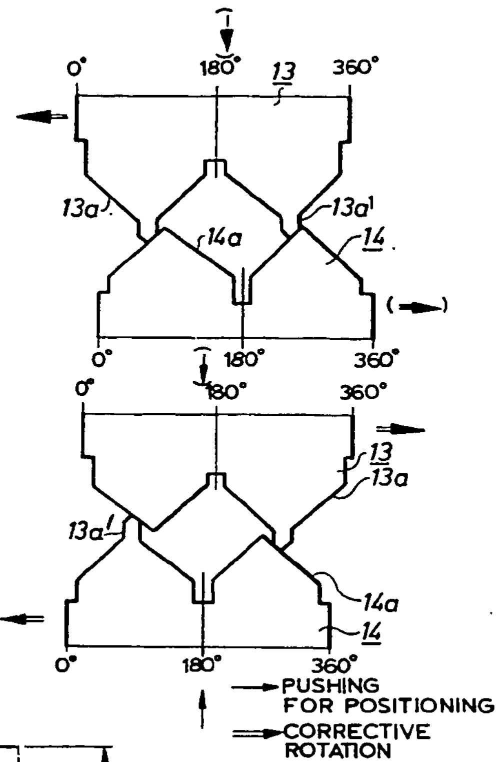


Fig. 5.

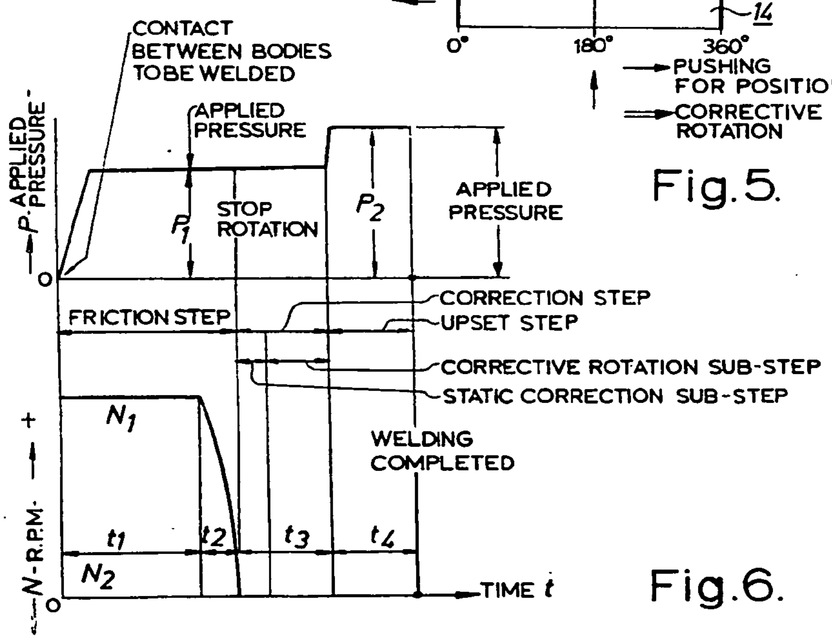


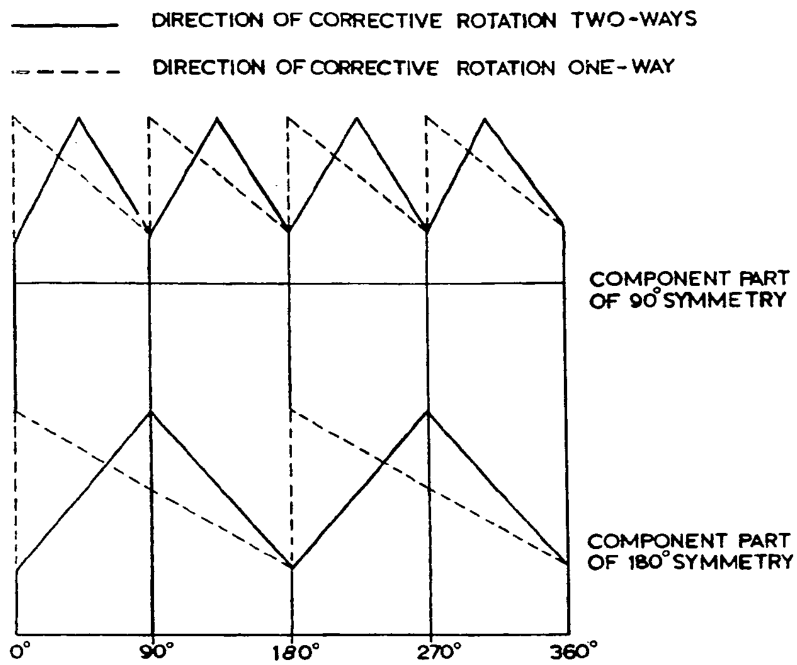
Fig. 6.

1382234 · COMPLETE SPECIFICATION

7 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 3

MITSUBISHI JIDOSHA KOGYO KABUSHIKI KAIS
COMPLETE SPECIFICATION NO:- 59813. A.D.1970.



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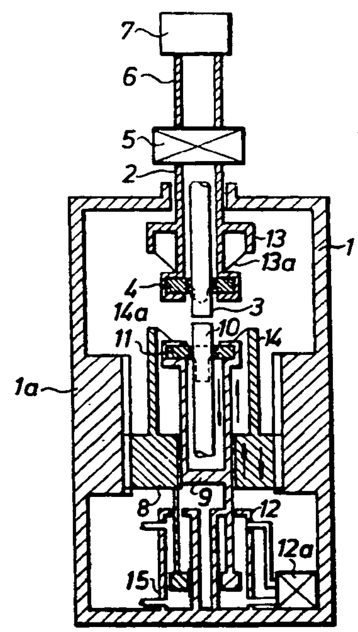
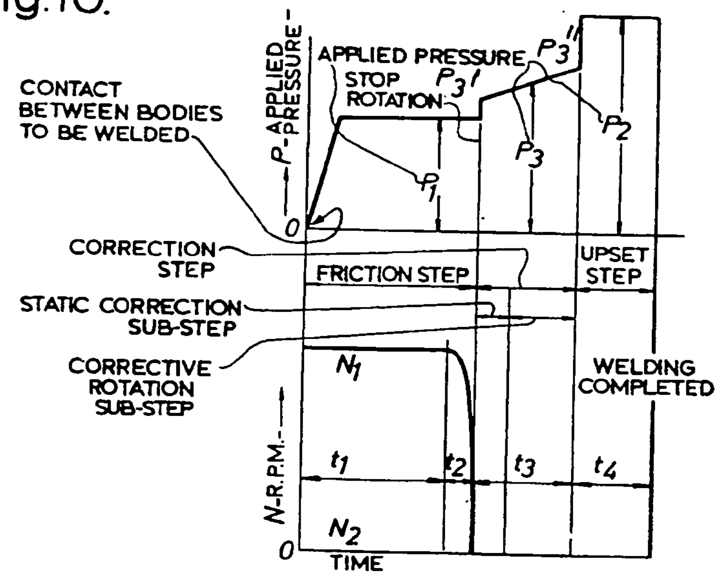


Fig. 8.

Fig.10.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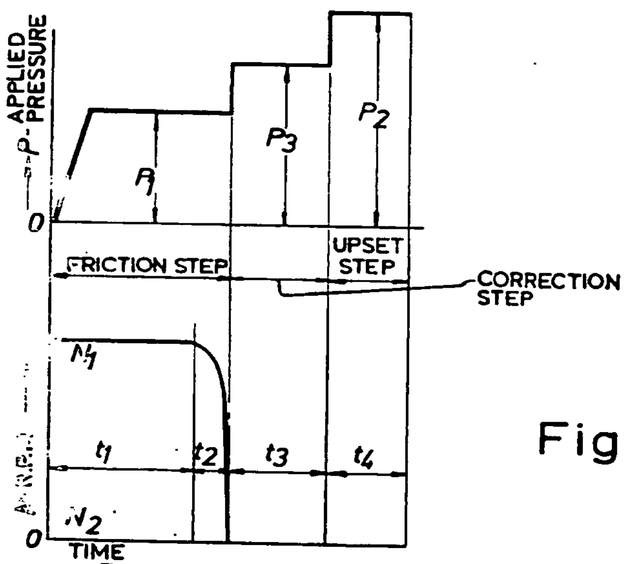
APPLIED PRESSURE
STOP ROTATION
CONTACT BETWEEN BODIES TO BE WELDED
P1
P3'
P3''
P3
P2
0
CORRECTION STEP
FRICTION STEP
UPSET STEP
STATIC CORRECTION SUB-STEP
CORRECTIVE ROTATION SUB-STEP
N1
WELDING COMPLETED
N-R.P.M.
t1
t2
t3
t4
N2
0
TIME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P3
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CORRECTION STEP
N1
t1
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t4
N2
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TIME

Fig.11.

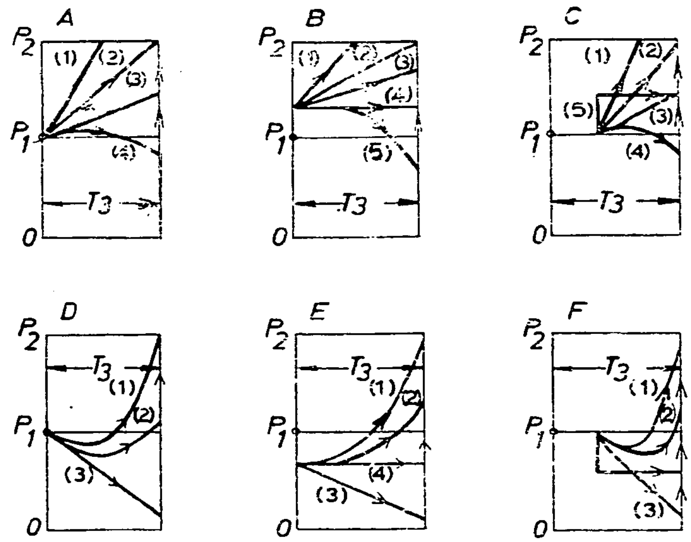

Fig.9.

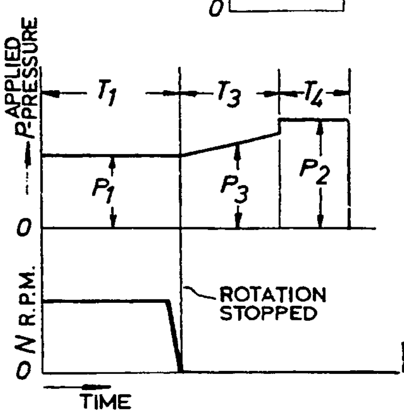

Fig.12.

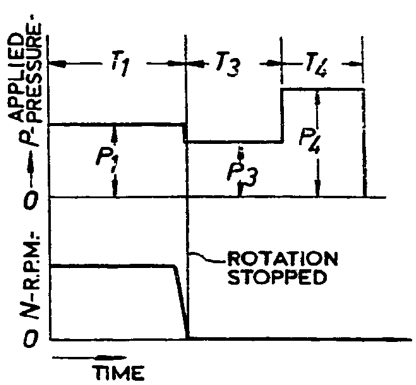

Fig.13.

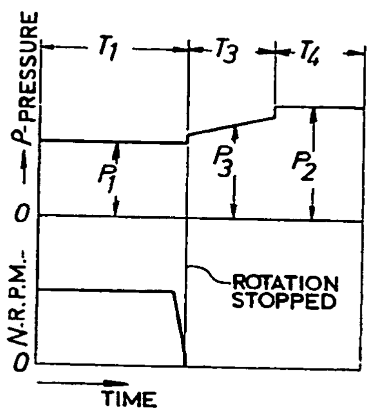

Fig.14.

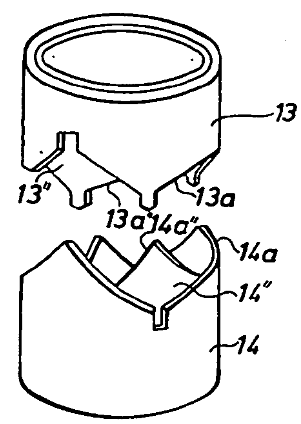

Fig.16.

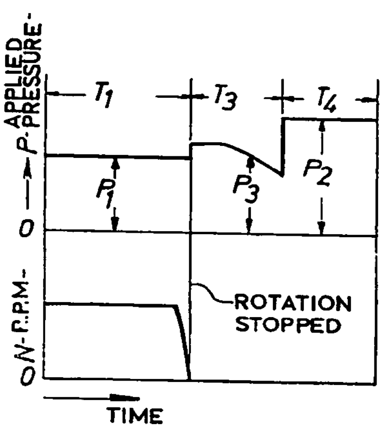

Fig.15.

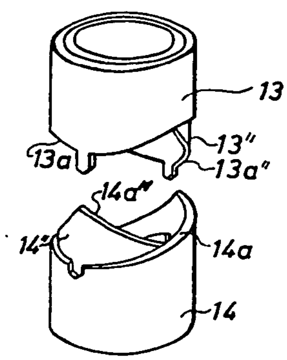

Fig.17.

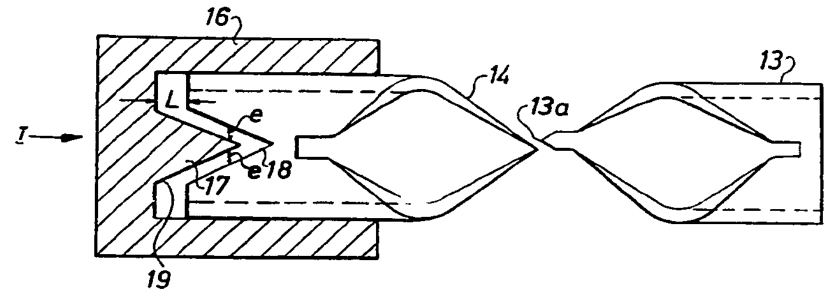

Fig.18.

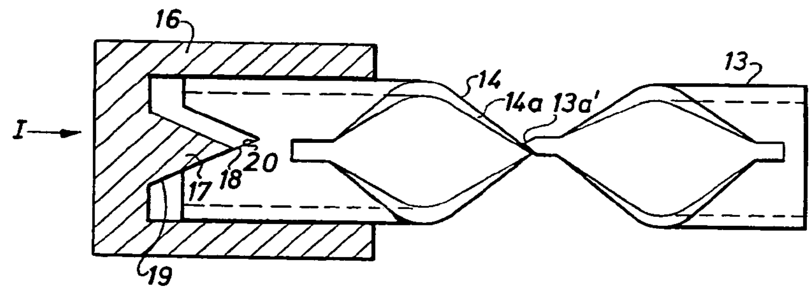

Fig.19.

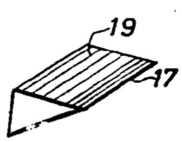

Fig.22.

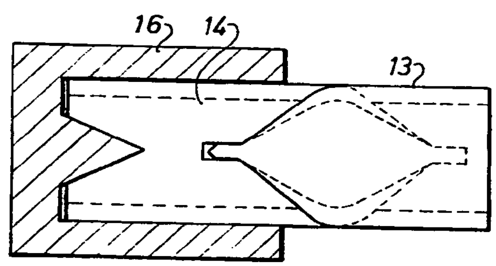

Fig. 20.

Fig. 21.